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16. ABSTRACT

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We provide here a more complete analysis of estimated benefits from reductions in troposphere ozone based on the final results of the NCLAN plant science research. In doing so, we concentrate on improvements in the modeling and underlying data which are reflected in this current assessment. While uncertainties still remain, these improvements would result in more defensible estimates of the magnitude of ozone's effects on U. S. agriculture.

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A Reassessment of the Economic Effects of Ozone on U.S. Agriculture

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The potential adverse effects of environmental change on agriculture have motivated considerable public research on this topic. Acid deposition, gaseous air pollutants, stratosphere ozone depletion and "green house" phenomena, individually and in combination, have been or are being evaluated in terms of effects on agricultural productivity. Assessments of the economic consequences of such effects have also been performed as input into the regulatory process. As with any applied bioeconomic analysis, the credibility of these economic assessments is dependent on the quality of the natural science and other data on the pollutant in question.

The ability of economists to assess the agricultural effects of one important pollutant, tropospheric ozone, has been improved by the recently completed National Crop Loss Assessment Network (NCLAN). The structure, protocols and initial plant science findings of this U.S. Environmental Protection Agency program have been presented in this journal (see, for example, Heck et al).[1,2] In a related article,[3] we reported the economic consequences of those preliminary ozone crop yield effects. Summary plant science findings have now been published.[4]

We provide here a more complete analysis of estimated benefits from reductions in troposphere ozone based on the final results of the NCLAN plant science research. In doing so, we concentrate on improvements in the modeling and underlying data which are reflected in this current assessment. While uncertainties still remain, these improvements should result in more defensible estimates of the magnitude of ozone's effects on U.S. agriculture.

The overall objective of this analysis is to provide an estimate of the economic effects of ozone on U.S. agriculture using the full set of NCLAN data. Performing such an analysis involves a multi-stage process in which plant science data (e.g., yield changes for selected crops under alternative ozone scenarios) are used to modify the yield and other parameters in a quantitative model of the U.S. agricultural economy. The subsequent changes recorded in certain economic dimensions of the model provide a measure of the economic consequences of those changes in plant science data.

This section discusses the structure and assumptions of the economic model used to translate yield changes into economic effects. Conceptually, the methodology is the same as that described in Adams, Hamilton, and McCarl.[3] The primary differences between the structure of the economic analysis reported in Adams, Hamilton, and McCarl and the economic specification used here include: (1) updating of parameters to reflect economic, agronomic and environmental conditions through 1983; (2) slightly greater spatial resolution (from 55 to 63 contiguous production regions) in the United States; (3) generalization of the analysis to a multi-year "base" period (1981–1983); (4) expansion of livestock components of the model; (5) adjustment of demand and supply elasticities to reflect changes in national and world markets; (6) greater disaggregation of ozone levels and more realistic modeling of plant exposure; (7) more specific scenarios concerning changes in ozone, including effects of a proposed seasonal standard; (8) more fully modeled adjustment for moisture stress; (9) the addition of hay, alfalfa, and rice to the crops included in the earlier analysis; and (10) modeling of uncertainties in both exposure-response estimates and meteorological data.

In application, the economic model captures two levels of economic response; the micro or farm level and the sector or aggregate level. The aggregate level response is represented in a price-endogenous mathematical programming model of the agricultural sector; i.e., an activity analysis spatial equilibrium model.[5] Multiple activities (within crops) based on historical crop mixes are used to generate the set of primary agricultural commodities that interface with the sector models. These primary commodities are listed in Table I. In addition to crops, the analysis also includes livestock products. An endogenous livestock component is needed, given that livestock are the principal "consumers" of commodities such as corn and soybeans.

The acreage relationships observed over time are used to develop a mix of crop activities from the USDA Farm Enterprise Data System (FEDS) budgets for these regions. This procedure is intended to provide an economically and technically realistic portrayal of farm level responses. The producer level responses generated through historical data are then combined with the sector model to obtain a measure of total social welfare associated with agricultural production and consumption.

The aggregate (sector) model features constant-elasticity-of-demand relationships for the outputs (commodities) of the micro model. The elasticities vary with end use and across domestic and export markets. Given the long-run nature of the model, export demands assume major importance. Export demand elasticities for

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Table I. Primary commodities included in the economic model.

Cotton	Sugar cane	Live heifers
Corn	Sugar beets	Live calves
Soybeans	Silage	Nonfed calves for slaughter
Wheat	Hay	Fed calves for slaughter
Sorghum	Milk	Calves for slaughter
Oats	Culled dairy cows	Hogs for slaughter
Barley	Culled dairy calves	Feeder pigs
Rice	Culled beef cows	

corn, sorghum, wheat, soybeans, soybean oil and soybean meal are derived from the USDA Policy Analysis Group.[6] The export elasticities vary, from −0.18 for cotton, to −0.82 and −0.80 for soybeans (whole) and sorghum, respectively. Assuming supply and demand functions which are integrable and independent of sector activity, first order conditions are then achieved in the model specification.

Table II. Secondary commodities in the economic model.

Soybean meal	Veal
Soybean oil	Nonfed beef
Poultry feed	Fed beef
Feed grains	Pork
Protein supplement dairy feed	Milk products
High protein swine feed	Low protein swine feed

The objective function is:

$$\text{Maximize: } c = \sum_i g_i(Z_i) - \sum_j e_j(X_j) - \sum_m C_m Y_m \quad (1)$$

where c is the sum of ordinary consumers' and producers' surplus. Following Samuelson,[8] the objective function may be interpreted as a measure of net social benefit. Analytically, this is defined as the area between the demand and supply curves to the left of their intersection. The demand functions are specified at the national level, as are aggregate production responses. The integrals are evaluated from zero to Z_i^*, representing the amount of the ith commodity produced and sold to consumers; and from zero to X_j^* for the amount of the jth factor used. The parameters are as follows:

$g_i(Z_i)$ is the area under the demand function for the ith product;

$e_j(X_j)$ is the area under the supply function for the jth factor;

C_m is the miscellaneous cost of production, Y_m, subject to a set of technical and behavioral constraints.

Given the micro and macro structure represented in this specification, the model solution simulates a long-run, perfectly competitive equilibrium. The full empirical details of the objective function are provided in Adams, Hamilton, and McCarl.[8]

Changes in the objective function (economic surplus) arising from different model assumptions simulate the economic effects of alternative ozone levels.[9,10] By imposing alternative ambient ozone assumptions on farm level behavior, as manifested in yield changes predicted by NCLAN response data, changes in production, consumption and associated economic surplus may be measured. Changes in consumers' and producers' surplus between alternative and current ambient ozone concentrations indicate the benefits (costs) for these alternative ozone levels.

Solution Procedure and Data Summary

The sector model is solved under constant-elasticity demand curves using the MINOS software package.[11] Basic data utilized in implementing the model are USDA FEDS budgets. The United States is disaggregated into ten regions consisting of the 48 states but with the Corn Belt (Iowa, Indiana, Ohio, Illinois, Missouri), California and Texas disaggregated into 22 subregions. This results in a total of 63 production regions. The primary crop coverage (commodities) is presented in Table I. Table II summarizes the secondary commodities arising from these primary items. In its current version, the FEDS budgets used in the analysis were updated to 1983, using 1983 yields, acreage, and prices. The modified budgets include transportation costs, chemicals, machinery, fuel and repairs, and interest. Demand levels for products and supply prices are drawn from 1983 agricultural statistics.

One feature of interest here is the export component. Since many U.S. commodities enter world trade, the economic model should contain a representation of world demand for these commodities. Eight primary commodities in the model enter world trade: cotton, corn, soybeans, wheat, sorghum, rice, barley, and oats. To reflect their respective demand situations, constant elasticity of export demand functions are assumed. As a part of the model solution, equilibrium prices, quantities, and consumer surplus for these eight export commodities are derived. This presents a measure of the effects of ozone levels (in the United States) on not only domestic producers and consumers but also foreign consumers (and indirectly, foreign producers). As a result, the transboundary effects of environmental policies in one country (the United States) can be observed in an aggregate sense by noting corresponding changes in foreign consumption and welfare.

Underlying Data and Assumptions

Data and assumptions from several disciplines are integrated to model the agricultural effects of tropospheric ozone. This includes the exposure-response data generated in the crop science experiments, the statistical analysis of those data, the calculation of regional ozone levels, and calculation of ozone exposures experienced by crops in each production region. Finally, these data are combined with producer and consumer responses via the economic model. In the model, consumers adjust consumption patterns as yield changes affect market prices and producers respond to both yield changes and endogenous price changes. This allows wide latitude in consumption and in cropping patterns which, in turn, has a major impact on the net effects realized by changes in ambient ozone levels.

The natural and physical science data that underlay the economic analysis are discussed in this section. The components, to be discussed in the following order, are (1) the exposure-response functions; (2) atmospheric ozone levels; growing seasons and "effective" ozone exposures received by the different crops in different states; (3) treatment of the effects of moisture stress; and (4) scenarios for changes in ambient ozone concentrations.

Exposure Response Functions

Exposure-response experiments have been carried out on cultivars of 14 distinct crops by NCLAN scientists over the last six years.[4] The economic analysis focuses on the eight major field crops (alfalfa, barley, corn, cotton, hay (a clover-fescue mix), sorghum,

Table III. Weibull model parameter estimates for NCLAN Data.[a]

Crop[b,c]	σ[d]	c	Correlation[e]
Alfalfa	178 (28)	2.07 (0.55)	−0.9367
Corn	124 (2)	2.83 (0.23)	−0.2300
Cotton	111 (5)	2.06 (0.33)	−0.5882
Forage	139 (15)	1.95 (0.56)	−0.9066
Soybeans	107 (3)	1.58 (0.16)	−0.5824
Rice	202 (50)	2.47 (1.10)	—[f]
Sorghum	314 (162)	2.07 (1.22)	−0.9734
Spring wheat[g]	186 (40)	3.20 (1.86)	—[f]
Winter wheat	137 (5)	2.34 (0.34)	−0.6625

[a] The Weibull is given by Equation 2 in the text. The α parameter is normalized to unity.
[b] Pooled data of all experiments for a given crop have been used to estimate the Weibull parameters. The number of experiments per pooled response is as follows: alfalfa-3; corn-6; cotton-5; forage-4; soybeans-21; rice-2; sorghum-1; spring wheat-3; winter wheat-2.
[c] 12 hour averages have been used except for rice, sorghum, spring wheat and winter wheat, which use 7-hour averaging times.
[d] Standard errors are in parentheses.
[e] This is the correlation between the parameter estimates.
[f] Error bounds for rice and spring wheat were taken from the sorghum estimate. This is an approximation, but these crops show only minor sensitivity to ozone.
[g] The estimates for spring wheat are those reported in Adams, Hamilton, and McCarl, 1984.

soybeans, and wheat) in this set. In addition, data from an experiment conducted for the California Air Resources Board[12] were used to estimate yield effects for rice.

The experiments involve fumigating crops in field chambers 7- or 12-hours per day at different ozone concentrations. Ozone levels are transformed into seasonal average exposures for each experimental treatment. Functional correspondence between seasonal exposures and yields is then estimated using the Weibull function. The flexible, nonlinear Weibull function is biologically reasonable and captures aspects of plant response to ozone that linear forms do not, with important economic consequences. The form of the Weibull function is:

$$y = \alpha \exp[-x/\sigma]^c \qquad (2)$$

Statistical fits were obtained from field experiments for each cultivar and site for each crop, as well as combinations (pooling of data) across crop cultivar experiments. The parameter estimates used in the analysis are presented in Table III, along with the standard errors and correlations. A detailed discussion of these data and statistical results is found in Lesser et al.[13] For this analysis, only the aggregate of all sites and cultivars of a crop (e.g., soybeans) are used. Selection of an aggregate or pooled response is motivated by several factors. First, the model focuses on aggregate economic analysis. While individual cultivars common to a particular region might show a different experimental result than the pooled response, on average the combined analysis is a more balanced representation of national level response. Further, since the pooled sample size is much larger than for individual cultivars, the analysis is less prone to spurious correlation than using a variety of individual results for different regions. This also avoids the problem of deciding which cultivar to use when multiple cultivars are grown in a given region. Finally, confidence bounds are available on the combined fits, allowing sensitivity analysis of the economic results to the precision in the response parameters.

It should be noted that the use of a pooled response is conservative (understates yield effects) because slightly larger yield effects would result from a given reduction in ozone if producers shifted cultivars in light of demonstrably different responses to ozone. The approach to measuring yield effects of ozone by using net dry weight is also conservative because it ignores quality aspects of yield. While no systematic analysis of yield quality has been instituted in the NCLAN program, it seems likely that crop quality may decline with yield. Shortle, Dunn, and Phillips[14] extend the analysis of yield effects by measuring changes in both oil and protein content of soybeans, but this is the extent of quantitative analysis of the issue.

Ozone Data and Assumptions

The NCLAN crop experiments characterize ozone exposures as a seasonal average of both daily 7- and 12-hour periods. These windows generally correspond to the period of the day with the highest ozone readings. While the exposure dynamics used in NCLAN are the subject of debate,[15-17] these response data have been subjected to considerable plant science peer review and are the most comprehensive set of data upon which to base policy analysis. Use of the NCLAN response functions requires information on ozone levels in agricultural areas consistent with the exposure measure used in these experiments. In previous assessments (e.g., Adams, Hamilton, and McCarl),[3] a spatial interpolation of EPA's Storage and Retrieval of Aerometric Data system (SAROAD) ozone readings served to provide rural ambient ozone estimates for use with the NCLAN response functions.

To capture the exposure dynamics of plants under ambient conditions, Lefohn et al.[18] calculated monthly averages on both a "maximum seven hour" and a "maximum twelve hour" basis for a five-year period. This was accomplished through use of a spatial interpolation procedure, kriging, applied to SAROAD values through 1985. Validation of the methodology was performed using sites not included in the original data set. The results found acceptable predictive ability, especially for areas characterized by a high density of monitoring stations and where topographic and atmospheric conditions lead to spatial homogeneity of ozone. In areas where these conditions do not hold, especially the West, there is greater uncertainty. Fortunately, except for California (which had a large network of monitoring sites), the agricultural output in such areas is modest.

The estimated regional seasonal 7- and 12-hour mean ozone levels reported by Lefohn et al.[18] for each year serve to define the actual base or benchmark level for use in the economic analysis. Since the economic model is intended to represent equilibrium behavior using recent data, the average ozone levels over the years 1981 through 1983 are used as the "base" ambient ozone. Changes from this base ozone level are then developed to simulate an alternative ozone environment, as described below.

Growing Windows

To approximate crop exposure to ozone, we model the growing season for each crop and region. Growing seasons vary within a state because producers have flexibility on planting (and hence harvesting) dates. There are also phenological periods when plants are more sensitive to ozone, e.g., during flowering of soybeans. This results in a distribution of plant growth (yield sensitivity) between the planting and harvesting dates. Finally, in most experiments, fumigations with ozone began several weeks after emergence. The ozone levels experienced by the plants during this early growth period were not included in the calculation of the ozone levels used to generate the exposure-response functions.

The development of weighted growing windows for each crop explicitly accounts for the distribution of planting

dates and growth rates for these crops, and for the experimental protocols which give rise to the exposure-response relations. By adjusting these dates and weights on a state-by-state and crop-by-crop basis, the estimated ozone exposures are intended to mirror real world exposures.

Moisture Stress

An important issue in the ozone analysis is the interaction with moisture stress, as moisture stress is one of the primary factors affecting yields of field crops in many regions of the United States. A number of NCLAN experiments were aimed at testing potential interactions between ozone and moisture stress. To address this relationship, King[19] modeled drought effects with a plant process model for the major crops (corn, soybeans, cotton, wheat, and forage) in the Corn Belt and adjacent areas. This simulation process projects diminished sensitivity to ozone when yields are concurrently reduced by moisture stress. Using disaggregated data provided by Control Data Corporation, alterations in the yield adjustments due to ozone are obtained.

The net effect of these adjustments is to lower modeled sensitivity of yields to ozone. However, because the exposure-response relationships incorporate experiments with a mix of moisture effects, areas which are not stressed (areas which received adequate rainfall in the 1981–1983 base period, or which were irrigated, as in much of the West), are assumed to experience slightly increased ozone sensitivity.

The details of the procedure can be found in King,[19] which provides adjustments for five major crops for 1980–1983. The results for 1981–1983 were combined in this analysis by averaging the effects across the three years using production weights. The years 1981, 1982, and 1983 involved, respectively, modest, low, and substantial drought stress. Use of this three-year period results in greater than average moisture stress, but the extent is diminished by using production weights, given that the drought year, 1983, had reduced harvested acreage due to the government payment-in-kind (PIK) program.

Scenarios for Changes in Ozone

Alternative ozone levels (scenarios) are required to simulate the economic effects of changes from current levels. Previous economic assessments use a range of assumptions in developing ozone changes. For example, Adams, Hamilton, and McCarl[3] hypothesize proportional changes in ozone levels from ambient in a specific year (e.g., 25 percent from 1980 levels). Adams, Crocker, and Katz,[20] Kopp et al.,[21] and Howitt and Goodman[22] specify seasonal average levels similar to the 7-hour seasonal average discussed above.

In this analysis, both proportional changes and changes linked to seasonal levels are evaluated. The proportional changes are calculated to provide a comparison with the results of the Adams, Hamilton, and McCarl[3] analysis. The latter case is meant to be suggestive of a seasonal standard for vegetative effects. Specifically, scenarios are developed to approximate one of the standards proposed by the EPA Office of Air Quality Planning and Standards.[23] The suggested standard is a seasonal average incorporating a three-month average of daily 7-hour averages. The 7-hour average is the daily average of the seven (consecutive) one-hour periods in a day with the highest average. The three-month average is the three consecutive months with the highest average; it also corresponds to the core of the growing season.

Any proposed seasonal standard must recognize the stochastic nature of air pollution and the weather and human elements which cause it. Because of pollution variability, current National Ambient Air Quality Standards (NAAQS) for ozone use the highest one-hour average on the second highest pollution day. To allow for this variability in evaluating a seasonal secondary NAAQS, scenarios are needed that reflect different probabilities that the seasonal standard will be exceeded in a given year. This stochastic aspect is important from a regulatory perspective, for if individual regions aim exactly at a standard, the distribution of air pollution events implies they will be in violation about half of the years.

To model the current ambient levels and their variability, we constructed three-month (seasonal) 7-hour averages for 1980–1984. Next, a sample standard deviation was calculated to reflect the representative intertemporal variability of each region. Given the mean and standard deviation, it is straightforward to construct an ozone level, X_i, which a region must aim at to satisfy the standard, say, 95 percent of the time. Thus,

$$X_i = S - k \cdot SD_i \qquad (3)$$

where S is the standard (for instance, 50 ppb ozone), SD_i is the sample standard deviation for state i, and k is the number of standard deviations needed for a given confidence level. For our sample of five years (1980–1984), a 95 percent probability level implies k = 2.132. This formulation assumes that the ozone variability is approximately normally distributed. An analysis of SAROAD ozone data for 1980–1984 in the Corn Belt indicates that this is approximately correct for individual sites using the analysis of residuals provided in SHAZAM.[24] Aggregation to state averages should strengthen this approximation.

From a regulatory perspective, if the state's long-term mean level $\bar{Z}_i$ is sufficiently low (below X_i, not just below the standard, S), there is no adjustment taken and state ozone levels remain unchanged. If the long-term mean exceeds X_i, then define the adjustment ratio, r_i, as:

$$r_i = X_i/\bar{Z}_i \qquad (4)$$

Table IV. Model prices and quantities vs. actual: 1981–1983.

Commodity	Prices		Quantities	
	Model	Actual	Model	Actual
	($ per unit)		(millions)	
Cotton	284.97	281.90	10.24	11.79
Corn	2.68	2.68	6,452.28	6,839.00
Soybeans	5.73	5.65	2,018.02	1,915.00
Wheat	3.56	3.50	2,260.78	2,419.00
Sorghum	2.53	2.50	662.00	730.00
Rice	8.13	8.01	120.00	145.00
Barley	2.23	2.20	425.18	498.00
Oats	1.55	1.67	503.04	526.00
Hay	62.08	65.76	76.82	82.00
Milk	13.35	13.65	1,283.61	1,359.80
Pork	169.54	165.90	139.38	151.70
Fed beef	232.27	239.70	135.81	156.25
Nonfed beef	131.44	145.15	87.60	78.37

Prices for all crops are dollars per bushel, except for cotton ($ per 480 pound bale), rice ($ per hundredweight), and silage and hay ($ per ton). Meat prices are $ per cwt. and are average retail prices for finished meat products.
Source: USDA, ERS, Statistical Bulletin No. 715, Washington, D.C.; USDA, *Agricultural Statistics, 1984*. Washington, D.C.

Table V. Comparison of current economic surplus estimates with 1984 assessment, in 1982 dollars.

Ozone assumption	Producers' surplus	Consumers' surplus	Total surplus
	Levels ($ millions)		
BASE[a]	21,220	139,676	160,896
	Changes ($ millions)		
Current			
+25%	−690	−1,363	−2,053
−10%	286	522	808
−25%	572	1,318	1,890
−40%	683	2,097	2,780
1984 Assessment[b]			
+25%	−650	−1,515	−2,165
−10%	403	296	699
−25%	754	1,074	1,828
−40%	1,047	1,590	2,637

[a] The base levels are from the current assessment which is in 1982 dollars and reflect an average of 1981–83 ozone, production, and moisture levels. Both assessments include adjustments for moisture stress (Analysis V of Adams, Hamilton, and McCarl).[9] The corresponding base values for AHM in 1982 dollars are 30,443, 134,503 and 165,087 millions for producers, consumers and total surplus, respectively.
[b] The 1984 assessment used 1980 as a base. The dollar totals reported here have been equated by using the CPI indexes for 1980 and 1982.

The ratio is used to multiply *all* monthly ozone levels in the state *i*. The smaller the ratio, the greater the ozone reduction necessary to meet the standard. Both the level of the standard, *S*, and the probability of exceedance parameter, *k*, determine the degree of control of the overall standard.

Results and Implications

Successful validation provides one indication that the economic model is appropriate for evaluating the effects of ozone on agriculture. To establish that the model is indeed a reasonable approximation to the agricultural sector over the period of interest, we test the endogenous prices and outputs with actual values for the base years, 1981–1983. Table IV provides a comparison of actual average prices and quantities with those determined by the model at 1981–1983 average ambient ozone and moisture stress conditions. As is evident from Table IV, the prices for all commodities match reasonably well (within 5 percent) while the quantities generally understate actual levels by 5 to 10 percent.

Comparison with the Previous NCLAN Assessment

Among the extant ozone economic assessments, the results of Adams, Hamilton, and McCarl[3] based on an earlier NCLAN data set, are of particular interest. To place these earlier results in perspective, we compare them with the results of the current analysis. It must be stressed that the present results reflect different exposure-response estimates and aerometric and economic conditions. Specifically, the current assessment is based on an average of 1981–1983 conditions, including foreign and domestic demand, technological conditions and levels of ozone and moisture stress. By comparison, the previous assessment was based on 1980 conditions. The economic models also differ in the extent of crop coverage, in that rice and alfalfa and other hays have been added. Further, the current assessment utilizes less ad hoc adjustments for moisture stress and reflects increased precision in the calculations of seasonal ozone exposures and in the response estimates for each crop.

The economic effects of the respective ozone change are captured by the *changes* in the objective function values for each ozone scenario when compared with the base solution. Table V contains the economic surplus values for the base case and the changes in economic surplus from that base for 10, 25, and 40 percent changes in ozone from 1981–1983 ambient levels. In addition, summary totals of aggregate economic surplus are provided for the earlier analyses, along with a breakdown of associated producer and consumer effects for both assessments. For consistency with the current analysis, the earlier results are drawn from the moisture stress case. The 1980 figures from the previous assessment have also been inflated by the Consumer Price Index (to 1982 dollars) to further facilitate comparison.

As is evident from Table V, in aggregate terms the economic effects across the two assessments are quite similar. For example, when ozone is reduced uniformly by 25 percent in all regions, the estimated economic benefits are $1.890 billion for the current assessment and $1.828 billion for the previous assessment (in 1982 dollars). The results for the 10 and 40 percent ozone changes reveal the same correspondence across the current and previous assessment (e.g., $2.780 billion vs. $2.637 billion for the current and previous assessments, respectively, at 40 percent ozone reductions). The similarities between the assessments in the face of distinctly different response, aerometric and economic conditions is attributable to some countervailing influences of those differences. Specifically, increased response sensitivity across crops and expanded crop cover-

Table VI. Changes in economic surplus arising from alternative ozone[a] scenarios: Constant percentage reduction vs. seasonal standards.

Ozone assumption	Total surplus	Producers' surplus	Consumers' surplus	Consumers' surplus: domestic	Consumers' surplus: export
	$ Millions			$ Millions	
−10%	808	286	522	313	209
−25%	1,890	572	1,318	738	580
−40%	2,780	683	2,097	1,127	970
50/95[b]	1,674	769	905	531	374
50/90	1,465	738	727	473	254
50/50	853	631	222	186	136

[a] Changes in economic surplus are the changes from the BASE values reported in Table V.
[b] These numbers refer to scenarios for changes in ozone levels. 50/95 is a 50 ppb seasonal standard with 95 percent probability of not exceeding the level in any given year, as explained in the text.

Table VII. Producers' surplus, by regions, in millions in 1982 dollars.[a]

Region	Baseline surplus	25% Reduction in ozone: Change in surplus	25% Reduction in ozone: Percent change	50/95 Ozone standard[b]: Change in surplus	50/95 Ozone standard[b]: Percent change	1984 Assessment[c]: Percent change
Northeast	126	25	19.76	39	30.95	4.36
Lake	1,858	36	1.94	−15	−0.81	1.04
Corn	5,836	278	4.76	475	8.14	3.18
N. Plains	3,096	34	1.10	3	0.10	0
Appalachia	1,266	102	8.06	120	9.48	2.87
Southeast	675	37	5.48	48	7.11	4.58
Delta	963	28	2.91	42	4.36	7.42
S. Plains	1,629	−27	−1.66	−17	−1.04	1.30
Mountain	2,384	44	1.85	−20	−0.84	2.47
Pacific	1,214	28	2.31	73	6.01	21.03
U.S. Total	19,047	584	3.07	779	4.09	3.04
Foreign	2,173	−12	−0.55	−10	−0.46	0
Total	21,220	572	2.70	769	3.62	3.04

[a] Totals may not add due to rounding.
[b] 50/95 is a 50 ppb 7-hour seasonal ozone standard with a 95% probability not exceeding the standard.
[c] 1984 is the 25% reduction from the Adams, Hamilton and McCarl[3] assessment. However, these changes come from a model without adjustment for moisture stress. Moisture stress would reduce the percentage changes listed here by a fifth, on average, and would especially affect the Corn Belt, Delta and Southeast regions.

age in the current assessment is offset by lower export demand, crop prices, and ozone levels in the 1981–1983 period.

Analyses of Seasonal Ozone Standards

This study differs from previous analyses by including potential *seasonal* standards in the ozone scenario evaluations. The seasonal standard analysis is intended to represent ozone conditions which would prevail if a state or region did not exceed the seasonal standard most of the time (e.g., 95 percent, or 19 years out of 20). By including the probabilistic aspects of the standard, the analysis attempts to capture both average levels (i.e., the assumed or desired seasonal average) and year-to-year variability in ozone (i.e., the percent of years the seasonal average is exceeded). For the purposes of this discussion, we focus on a seasonal standard of 50 ppb. As discussed below, the economic consequences of this standard are close to the net aggregate benefits achieved with a proportional 25 percent reduction in ozone. This standard also falls midway in the range of potential seasonal standards (40–60 ppb) suggested by OAQPS.[23] The 50 ppb standard is sufficiently high that some states do not violate the standard, while other states must reduce pollution levels substantially.

Changes in economic welfare are analyzed for both the 25 percent reduction and the 50 ppb (95 percent) seasonal standard by comparing changes in producers' and consumers' (both domestic and foreign components) surplus, as reported in Table VI. In addition to these central cases, several variations are also presented in Table VI to allow assessment of the sensitivity of the estimates to the extent and nature of ozone reductions. For percentage changes, these are the 10 and 40 percent reductions. For the seasonal standard the probability of compliance is varied; i.e., the 50 ppb standard with both 90 and 50 percent compliance levels.

The aggregate benefits of a 25 percent reduction and a 50 ppb standard with 95 percent compliance (50/95) are similar, $1.890 and $1.674 billion, respectively. In aggregate terms, producers gain relatively more with the seasonal standard than with the constant 25 percent rollback (46 vs. 30 percent of total benefits). This difference is due to the regions (and hence the crops) which are most affected. The inclusion of an endogenous livestock sector also allows regional producers to capture a greater share of those respective yield increases. The distribution of consumer gains is stable across the two scenarios. Unlike the previous assessment, domestic consumers now obtain over half (56–59 percent) of the benefits. This reflects the diminished impact of the export sector during the period modeled in the current assessment.

At the regional level the distribution of producer gains differs markedly between the seasonal standard and the constant percentage reduction. These regional implications are presented in Table VII. Producers in higher ozone areas, especially those with greater variability, gain most with the 50/95 standard. The Northeast, Corn Belt, Appalachia, and Southeast regions all gain substantially. These gains come at the expense of lower ozone regions of the Lake states, Northern and Southern Plains and Mountain areas. This is due to relatively low ozone levels in these regions (and hence little yield improvement), while crop prices decline by the same amount across all regions. The regional aggregation masks more extreme differences within some regions. For instance, the Pacific region is composed of California (two regions), Oregon and Washington where the ozone reductions are 35, 22, 0, and 0 percent, respectively. California producers gain substantially while those in Washington and Oregon suffer from the decline in product prices associated with reduced ozone (and increased output).

As noted before, the 50 ppb standard is midway in the range of seasonal standards discussed by OAQPS. Alternative seasonal levels can be tested (e.g., 40 ppb) at the 95 percent compliance level. The compliance parameter can also be varied. Such variations dramatically affect the economic benefits. Referring back to Table VI, for 90 and 50 percent compliance with a 50 ppb standard (50/90, 50/50), respective increases in economic surpluses of $1.465 and $.853 billion result. In all cases, the gains of modest ozone reduction accrue mainly to producers (over half for the 50/90 standard), while greater reductions consistently favor consumers. Consumer benefits favor the domestic sector, a reversal from the 1984 assessment which reflects changes in international markets.

An implication of these preliminary evaluations of seasonal standards is

Table VIII. Evaluation of the interaction between ozone reductions and 1985 farm program provisions.

Ozone scenario and farm bill assumptions[a]	Change in economic surplus	Change in estimates	
	($ millions)	($ millions)	(%)
25% reduction			
Without farm bill[b]	1,890		
With farm bill			
0/0	1,752	138	7.1
10/25	1,621	269	14.2
20/50	1,417	473	25.0
50/95 standard			
Without farm bill[c]	1,674		
With farm bill			
0/0	1,556	118	7.0
10/25	1,438	236	14.0
25/50	1,262	412	24.5

[a] 0/0, 10/25%, etc. are the percentage of loan costs which end up as a net cost for cotton/feed grains, as explained in the text.
[b] Corresponds to analysis 2 reported in Table VI.
[c] Corresponds to analysis 4 reported in Table VI.

that the degree of compliance is an important element in setting a standard. Ignoring year-to-year variability in implementing a seasonal standard would be similar to choosing a standard with only a 50 percent chance of not exceeding that seasonal level. Further, from a regulatory perspective, it would appear unreasonable to assess the impact of a standard by assuming that all regions exactly equal the proscribed level.

Impact of Ozone Standards on U.S. Farm Programs

Due to government intervention, the U.S. agricultural sector typically responds to a mix of market and institutional signals. Since agriculture is also affected by other government policies, its status as a revenue-supported industry may have implications when examining effects of interactive policies. For example, McGartland[25] has questioned past estimates of benefits from ozone reductions because farm program provisions and resulting surplus production were not modeled.

One reason such interactive analyses are lacking is the difficulty in modeling interactions between long-term environmental policies and U.S. Farm Program provisions. Since farm programs vary from year to year, depending on economic and environmental conditions worldwide, it is questionable whether short-term farm program provisions can or should be included in any economic analysis intended to model long-run or equilibrium conditions. There are also practical difficulties in imposing the current farm program provisions on the current economic model. For example, the economic model is tuned to economic, technological and environmental conditions for the 1981–1983 period. The farm bill provisions at the time of this analysis, however, are specific to 1985 conditions. Ozone and moisture stress data for 1985 were not available at the time of this assessment. Thus, evaluation of ozone-induced supply on farm bill payments requires that provisions of the 1985 Farm Bill be imposed on 1981–1983 economic conditions.

Recognizing these difficulties, we address one major feature of the 1985 Farm Program by incorporating the target price response at the producer level. The procedure we use here to obtain an impression of the effects of ozone reductions on farm program payments consists of three stages. In the first stage the target prices are introduced for crops covered in the 1985 Farm Program (cotton, corn, wheat, rice, barley, sorghum, oats, and soybeans—the latter is only covered by loan provisions). Producers are presumed to use the target prices as their expected market prices. Stage two fixes the quantities of program crops in the model at the levels determined by producer response to the target prices in the first stage. Market clearing prices for these new quantities result from the Stage two solution. The difference between the target price (Stage 1) and the market clearing price (Stage 2), is equal to the per-unit deficiency payment (constrained to be non-negative). This per-unit deficiency payment, times the quantity produced, is the total deficiency payment for each program crop. The third stage consists of repeating the first two stages using the yield adjustments occasioned by changes in ambient ozone levels. Payments for crops taken under loan are also calculated.

Comparison of the farm program solutions, including the deficiency and loan payments before and after the ozone adjustment, provides an estimate of the 1985 Farm Program provisions on the benefits arising from reductions in ozone levels. Since the cost of loan provisions is dependent on the value of resultant stocks (under ozone changes), some assumptions are required concerning how these costs vary by crop. In a long-run equilibrium, the marginal (expected) value of an additional unit of inventory is equal to costs associated with holding that unit (i.e., interest, storage and spoilage costs). Thus, a first case is to assume that there are no net costs associated with holding of stocks. In addition to this assumption of zero net cost of loan provisions, we also include two, more pessimistic, projections: holding costs-net-of-inventory-value are set at 10 and 20 percent (of the loan price) for cotton and 25 and 50 percent for corn. Cotton accounts for 80 percent of the change in loan payments, corn the remainder.

The results of this procedure are reported in Table VIII. The inclusion of the target price provisions reduce the benefits of ozone control reported in the "Without the 1985 Farm Bill" analyses (e.g., Tables V and VI) between 7 and 25 percent depending on assumed net inventory loan costs. If one assumes some moderate holding costs (e.g., 10 percent for cotton, 25 percent for corn) the existence of these farm program

Table IX. Sensitivity of economic effects to exposure-response and aerometric data uncertainties.

Ozone assumption	Benefits in $ Millions				
	Benchmark estimate[a]	Exposure-response bounds		Ozone data bounds	
		Lower	Upper	Lower	Upper
25% Reduction	1,890	1,444	2,356	1,854	1,927
50/95 Standard	1,674	1,335	2,031	1,605	1,745

[a] The benchmark estimate includes the baseline ozone data and exposure-response estimates, as reported in Table VI.

provisions under a seasonal ozone standard reduces the benefits of that standard by about 14 percent. These aggregate adjustments come at the expense of domestic and foreign consumers; domestic producers gain. Under the conditions of this analysis, reductions in the benefit estimates are more modest than suggested by McGartland.[25]

There are several shortcomings in this analysis. The farm program requires acreage set-asides as a condition of participation which have not been directly incorporated in the analysis. The impact is to overstate output (for both ambient and reduced ozone solutions). This inflates the size of the deficiency "price" and the quantity to which it applies. Second, there are both loan and payment limit provisions. These factors combine to limit participation to between 35 and 90 percent of available acreage, depending on the crop. Participation is a farm-level decision which cannot be fully modeled here because it depends on farm size, farm-specific historical yields and the relative productivity of marginal land. Finally, it is worth noting the conclusion of Segerson,[26] that it may be inappropriate to reduce the calculated benefits from ozone control by the cost of potential increases in farm supports arising from that new (more restricted) standard. Rather, the changes in farm payments are the increased cost of the current farm program under the new "technological" conditions defined by the change in environmental quality.

Sensitivity Analysis

While the current assessment represents an improvement in plant science and aerometric data over previous assessments, there is still considerable uncertainty remaining in these data. The sensitivity of the economic estimates to two sources of uncertainty, the response function estimates and the ozone data, are explored here. Imprecision in the exposure-response estimates is captured by calculating 95 percent confidence intervals around the respective crop response curves using the standard errors from the pooled response for each crop. These are used to provide bounds on the estimated benefits. As noted by Lesser et al.,[13] these standard errors probably underestimate the variability in the response because they do not account for environmental conditions at each site. Conversely, because the errors across equations are not completely correlated, using 95 percent confidence intervals for each crop response results in an *aggregate* confidence level on the economic benefits higher than 95 percent. How these two contervailing factors influence the validity of the confidence interval estimates is uncertain. Qualitatively, the resulting economic changes are similar to those reported in Table VI, though the magnitudes are altered. The sensitivity results are presented in Table IX. For the two ozone scenarios, the upper (lower) bounds are 20 to 25 percent higher (lower) than our benchmark estimates.

Uncertainty in the ozone data is evaluated using the standard errors on the kriged ozone levels. Typically, these standard errors are on the order of 3 to 8 percent of the ozone levels. If these errors are independent, then aggregate economic benefits will be unaffected because the errors tend to cancel out (by the law of large numbers) when averaging across the four to six months of the growing season, the three years (1981–1983) and the 63 production regions in the model.

Temporally, it is expected that the errors will be completely uncorrelated. However, because a network of adjacent monitoring sites is used in the kriging process there is some correlation spatially. To approximate the effects of spatially correlated errors, we assume that, on average, every four states have completely correlated errors but these groupings are mutually uncorrelated. These groupings are combined with the uncorrelated errors in the time domain to yield an overall 95 percent confidence interval for the benefit estimates. The 95 percent confidence intervals use the base ozone levels ± 1.96 · SE. The standard error (SE) is approximately the individual standard errors times k where $k = 1/n_1 \times n_2$ (= 0.0686); n_1 = average number of months of data and n_2 is the number of independent regions.

As a result of the relatively small magnitude of the kriging errors themselves, and the independence of those errors, the interval estimates due to uncertainty in the ozone levels are quite narrow (see Table IX). For the 25 percent reduction they are ±$36 million (2 percent) while for the 50/95 standard they amount to ±$70 million (4 percent). The effect of uncertainty in the case of a standard will be larger than for comparable percentage rollbacks because the starting point in the standard is changed while the ending point is unaffected. To see this, consider a region with an initial ozone level of 60 ppb (and a standard deviation over time of 2.5 ppb). A 25 percent reduction and a 50/95 standard both imply an average level of 45 ppb. However, if the regional ozone level was initially 64 ppb, a 25 percent reduction would imply a level of 48 ppb after control while the standard still implies 45 ppb.

We note that the marginal value of additional biological response (such as greater precision of the exposure-response functions) in defining aggregate economic effects declines relatively quickly. One reason for this is that the aggregate economic effects are summed over a large number of crops and growing regions, averaging out by the law of large numbers. It also reflects the value of the current collection of data which have resulted from the NCLAN research program.

Conclusion

The NCLAN program was established by EPA to gain a better understanding of ozone's effects on major agronomic crops and to assign economic values to those effects. Over the seven years of the NCLAN program, a series of preliminary economic assessments of the effects of ozone on U.S. agriculture were conducted. This paper provides a reassessment of those economic effects using the final set of plant science and ozone data from the now completed NCLAN program.

Results from this current assessment confirm findings of earlier efforts; namely, that ozone pollution imposes substantial economic costs on society. Specifically, increases in the yields of eight NCLAN crops associated with a 25 percent reduction in ambient ozone from 1981–1983 levels results in a benefit of approximately $1.9 billion (in 1982 dollars). Rollbacks of ozone by 40 percent reveal net benefits of almost $3 billion. Including farm program target price provisions in the analysis does not appreciably affect the magnitude of these benefit estimates. While the general range of benefits parallel earlier NCLAN assessments, the current values are generated from more accurate exposure-response and aerometric data, and greater spatial resolution and crop coverage than those earlier studies. The current estimates are strengthened by these refinements.

A unique feature of this analysis is the evaluation of seasonal, rather than hourly, standards for vegetation that reflect alternative exceedance rates arising from the stochastic nature of pollution events. Analysis of a seasonal standard indicates that the magnitude of potential benefits are similar to some recorded with the constant percentage rollbacks but the distributional consequences are substantially different. For example, a seasonal standard of 50 ppb with 95 percent probability of not exceeding the level in each region would produce approximately $1.7 billion (in 1982 dollars) in benefits, about the same amount as in the 25 percent rollback. However, the regional implications are quite different, with those areas with the greatest air quality improvement realizing the greatest gain. Producers in areas al-

ready in or near compliance may actually lose due to a decline in crop prices nationally from increased supply.

The analysis reported here is based on what we believe are the best available biological and meteorological data. The economic model also provides a reasonable representation of the key economic dimensions of agriculture. However, neither the natural and physical science data nor the economic model are free of potential errors. Some of the same limitations noted in earlier assessments apply here, including (1) continued extrapolation from a limited set of crops and cultivar responses to represent regional or national response; (2) uncertainty and disagreement concerning appropriate exposure measures; (3) relatively few data points on response surfaces at below ambient levels; (4) measurement and interpolation errors in developing rural O_3 estimates; (5) uncertainties in linking proposed standards to observed O_3 levels in rural areas; (6) potential errors in export and other demand elasticities used in the economic model to short-run or disequilibrium situations. These (and perhaps other) limitations must be noted.

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